REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE** Technical Papers	**3. DATES COVERED** *(From - To)*
4. TITLE AND SUBTITLE		**5a. CONTRACT NUMBER**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		**5d. PROJECT NUMBER** 2302
		5e. TASK NUMBER M1G2
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFMC) AFRL/PRS 5 Pollux Drive Edwards AFB CA 93524-7048		**8. PERFORMING ORGANIZATION REPORT**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory (AFMC) AFRL/PRS 5 Pollux Drive Edwards AFB CA 93524-7048		**10. SPONSOR/MONITOR'S ACRONYM(S)**
		11. SPONSOR/MONITOR'S NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Leilani Richardson
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	A		**19b. TELEPHONE NUMBER** *(include area code)* (661) 275-5015

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

3k separate items are enclosed

1115

1119

G2

MEMORANDUM FOR IN-HOUSE PUBLICATIONS

FROM: PROI (TI) (STINFO) 1 Oct 98

SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-1998-169 Tim Miller "Mode Mixity Determinations for Interfacial Cracking in Incompressible Materials Under Plane Strain Conditions (Presentation for paper AFRL-PR-ED-TP-1998-075 cleared 5 May 98)

Presentation Only **(Statement A)**

B2588.

Mode Mixity Determinations for Interfacial Cracking in Incompressible Materials Under Plane Strain Conditions

T.C. Miller

Air Force Research Laboratory
Edwards Air Force Base, California

October 1998

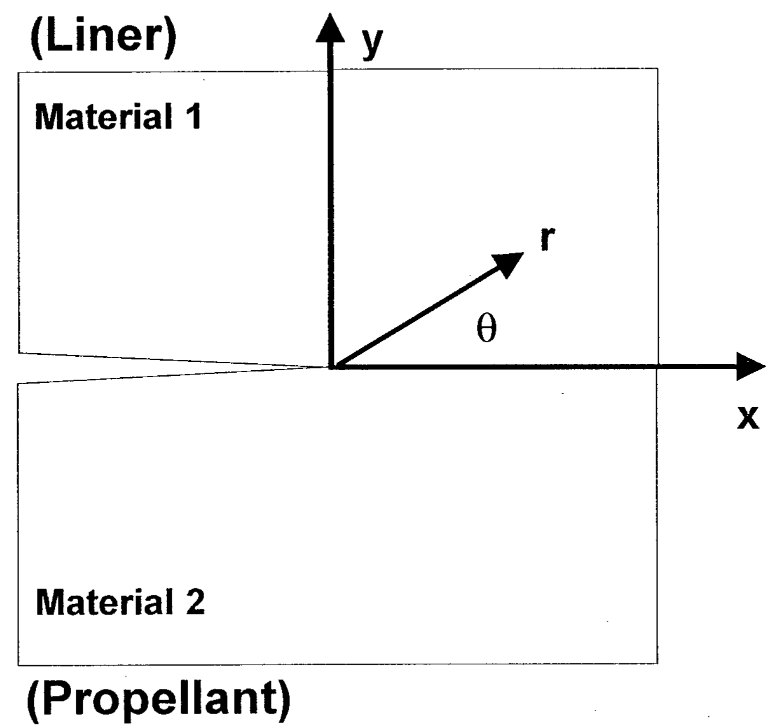
20021119 115

B2588.

Introduction

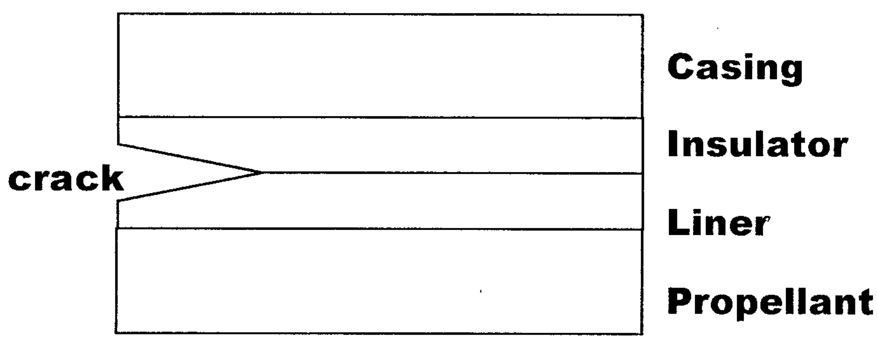
Liner - Propellant Failures

1. Materials are Incompressible
2. Plane Strain Conditions Exist
3. E_2/E_1 Varies with Materials Used

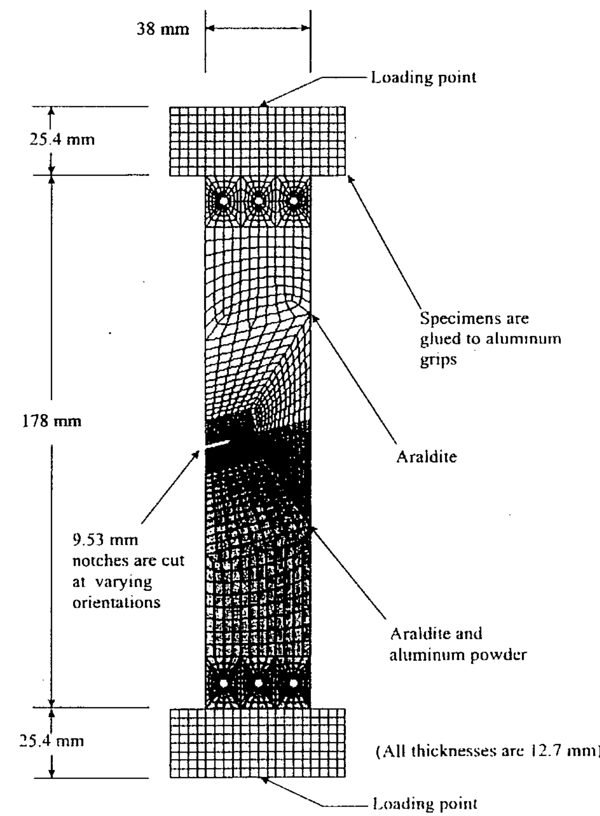


Specimen Geometry and Related Application

Applications to Composite Structures

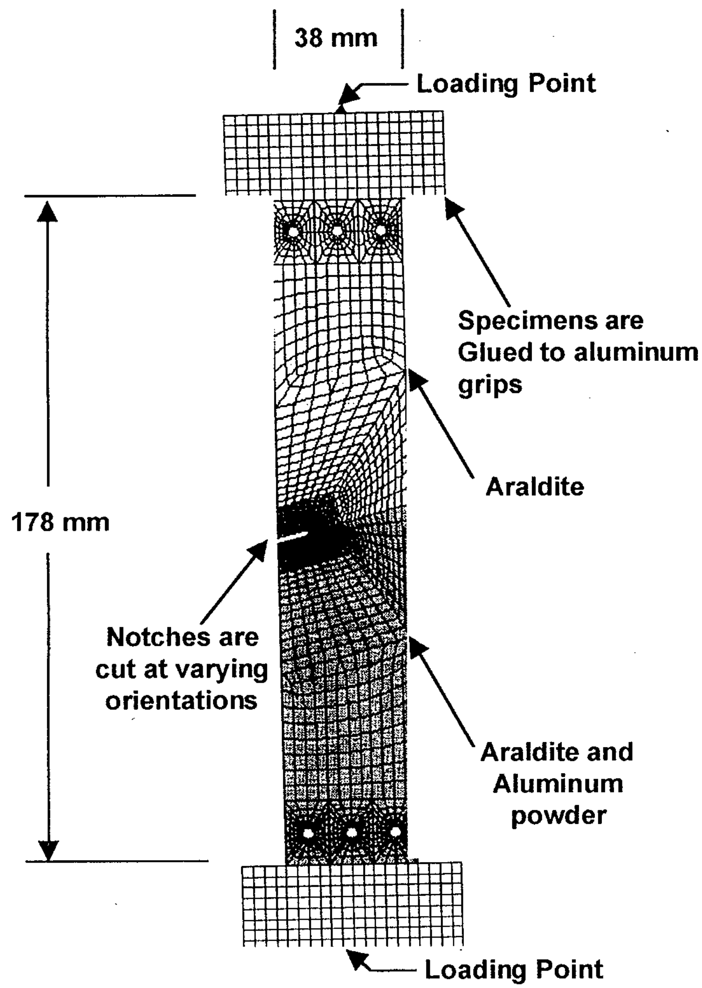


Related Photoelastic Stress Freezing Experiments



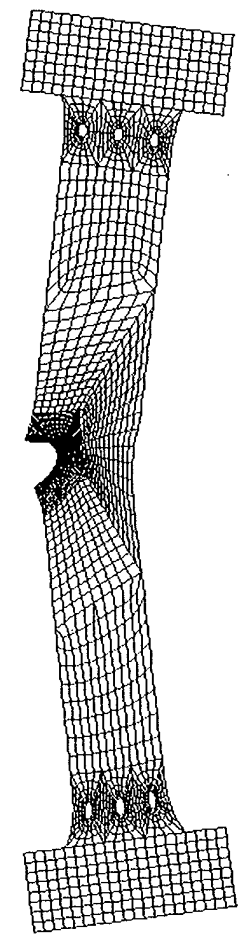
B2588.

Modeling of Incompressible Bimaterials Under Plane Strain Conditions



Typical Finite Element Model - Crack Orientation = 15 Degrees

- Both homogeneous and bimaterial specimens are considered
- Mode mixity is varied by changing crack angle (0, 15, 30, 45 degrees).



Loaded Specimen in Deformed Configuration

Incompressible Bimaterial Pans Under Plane Strain Conditions

General Interfacial Fracture

$\epsilon \neq 0 \qquad \beta \neq 0$

$$\sigma_{pq} = \frac{1}{\sqrt{2\pi r}}\{Re(\boldsymbol{K} r^{i\epsilon})\Sigma^{I}_{pq}(\theta) + Im(\boldsymbol{K} r^{i\epsilon})\Sigma^{II}_{pq}(\theta)\}$$

$$(\sigma_{yy} + i\sigma_{xy})_{\theta=0} = \frac{\boldsymbol{K} r^{i\epsilon}}{\sqrt{2\pi r}} = \frac{K_1 + iK_2}{\sqrt{2\pi r}}\,[\cos(\epsilon Lnr) + i\,\sin(\epsilon Lnr)]$$

$$J = G = \frac{\Lambda_1 + \Lambda_2}{16\cosh^2(\pi\epsilon)}\,|K|^2$$

Plane Strain/Incompressible Materials

$\epsilon = 0 \qquad \beta = 0$

$$\sigma_{pq} = \frac{1}{\sqrt{2\pi r}}\{Re(\boldsymbol{K})\Sigma^{I}_{pq}(\theta) + Im(\boldsymbol{K})\Sigma^{II}_{pq}(\theta)\}$$

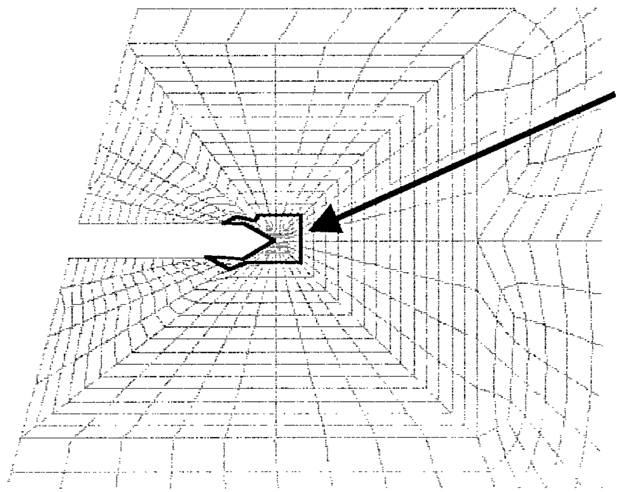
$$(\sigma_{yy} + i\sigma_{xy})_{\theta=0} = \frac{\boldsymbol{K}}{\sqrt{2\pi r}} = \frac{K_1 + iK_2}{\sqrt{2\pi r}}$$

$$J = G = \frac{K^2}{\overline{E^*}}, \qquad \frac{1}{\overline{E^*}} = \frac{1}{2}\left[\frac{1}{\overline{E_1}} + \frac{1}{\overline{E_2}}\right], \qquad \overline{E_1} = \frac{E_1}{1 - \nu_1^2}, \qquad \overline{E_2} = \frac{E_2}{1 - \nu_2^2}$$

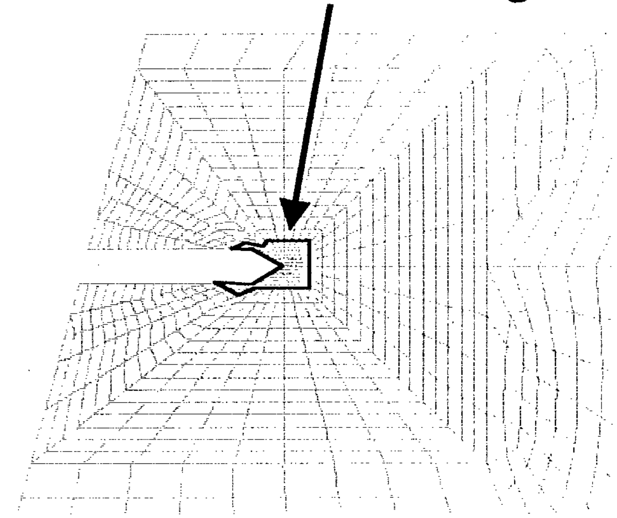
B2588.

Method for Characterizing Complex Stress Intensity Factor in Bimaterial Problems

Magnitude Assessment



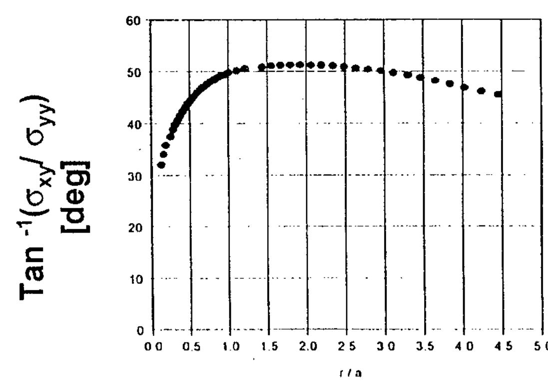
Gauss Divergence Theorem

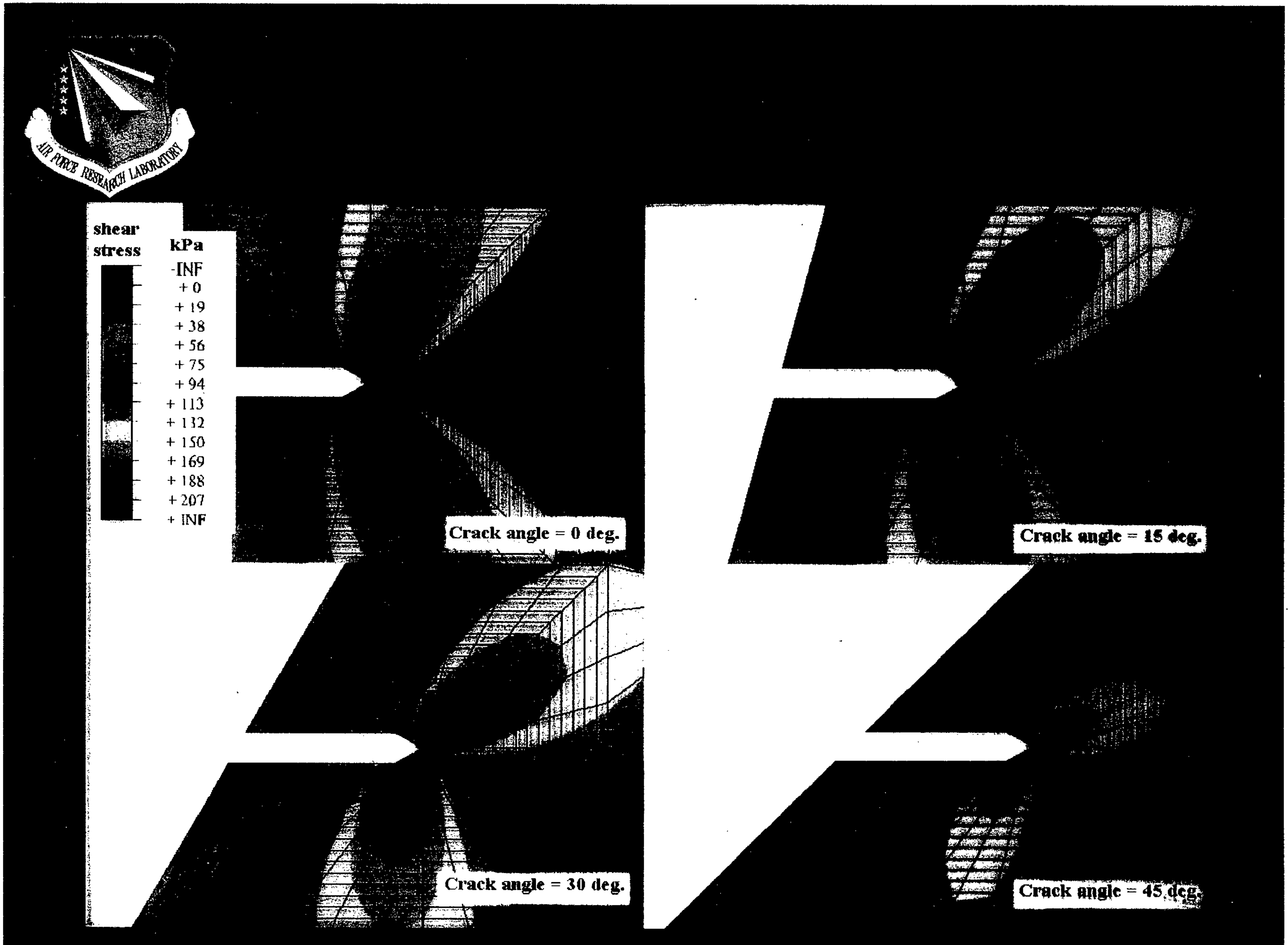


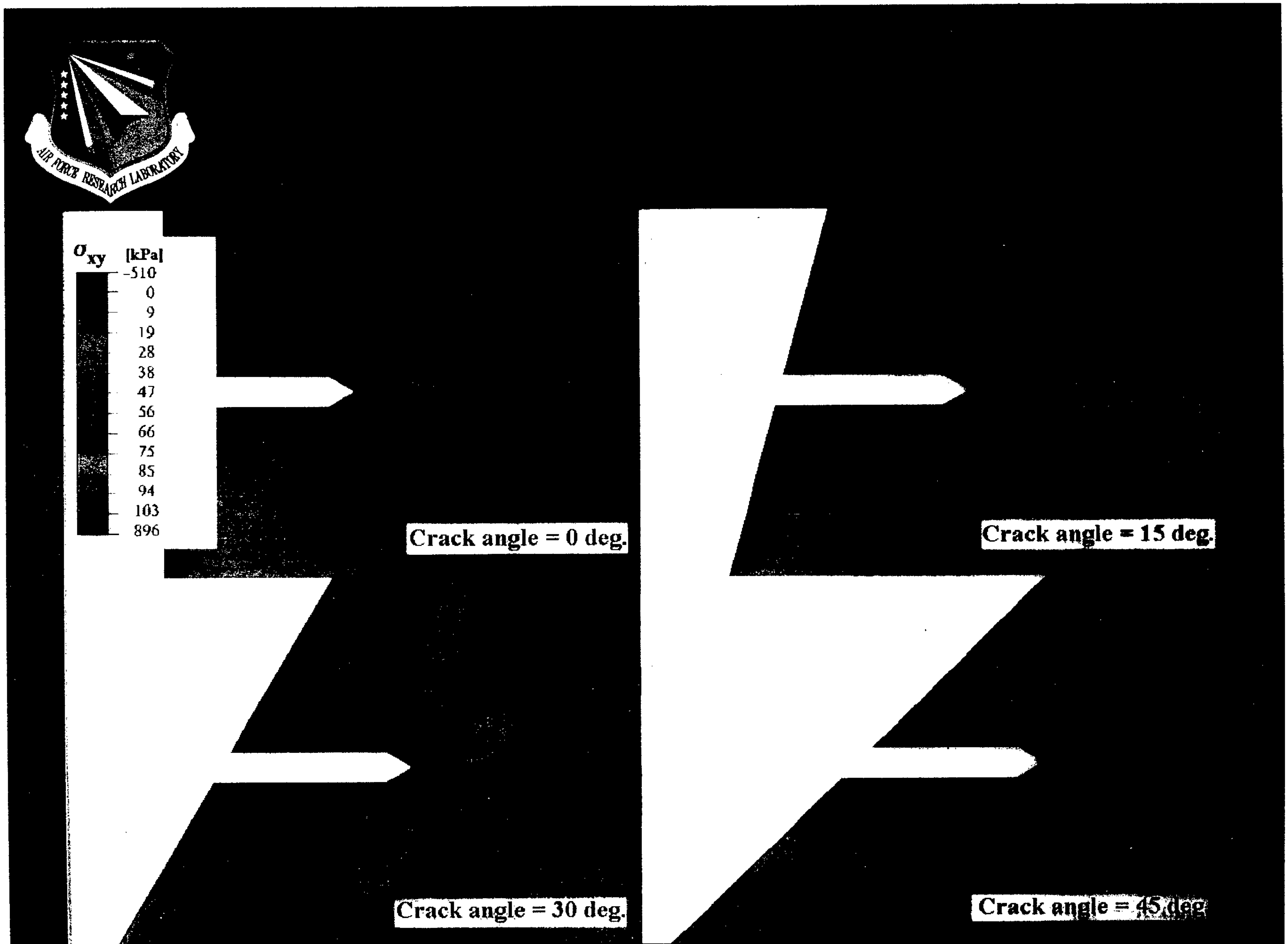
J as Contour Integral — **J as Equivalent Area Integral**

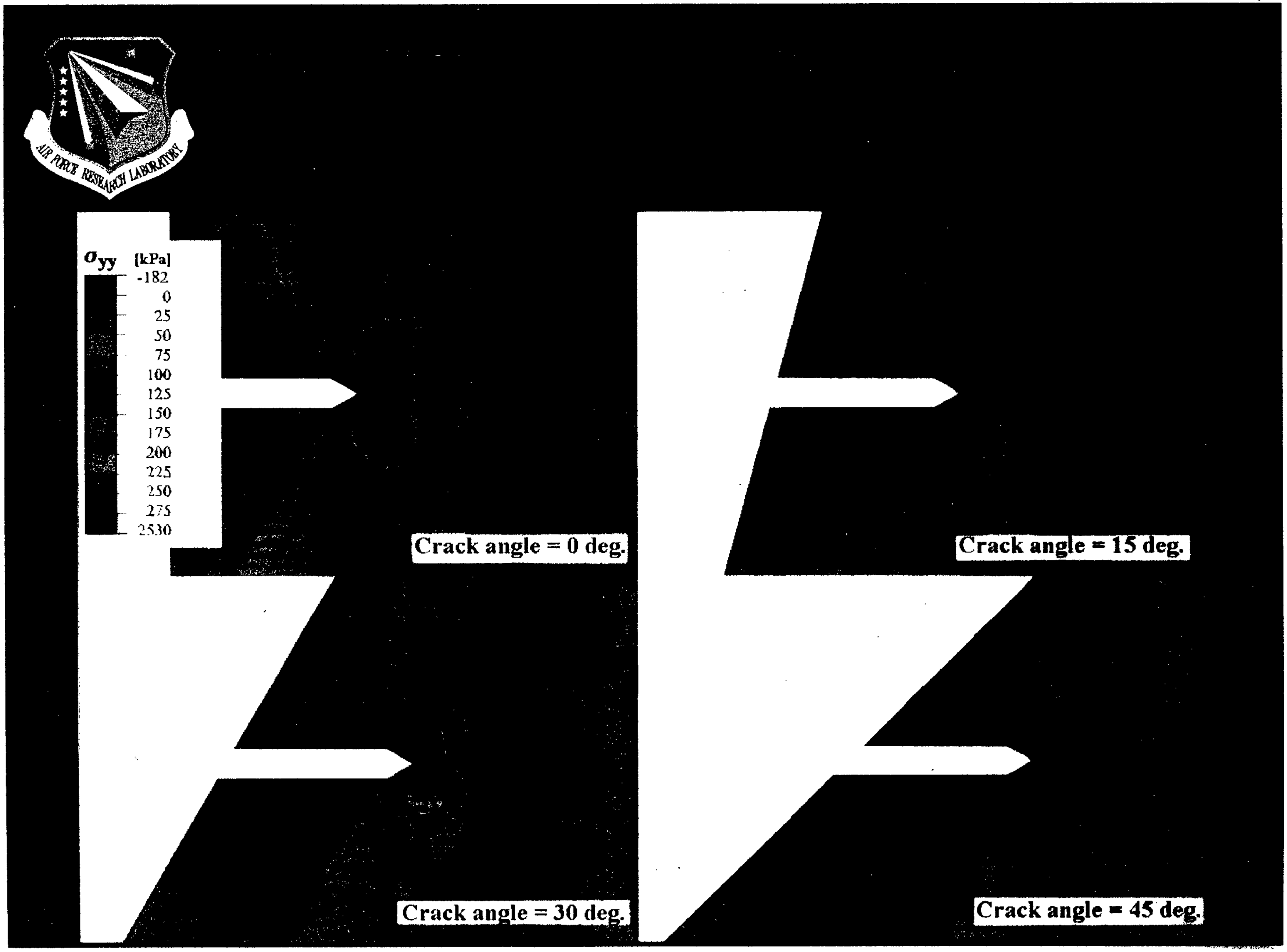
$J = \int_A [\sigma_{ij} u_{j,1} - w d_{1i}] q_{1,i} \, dA$, $|K| = \sqrt{J \overline{E}^*}$, $\overline{E}^*$ = Effective plane strain modulus, $1/\overline{E}^* = 1/2\,(1/\overline{E}_1 + 1/\overline{E}_2)$

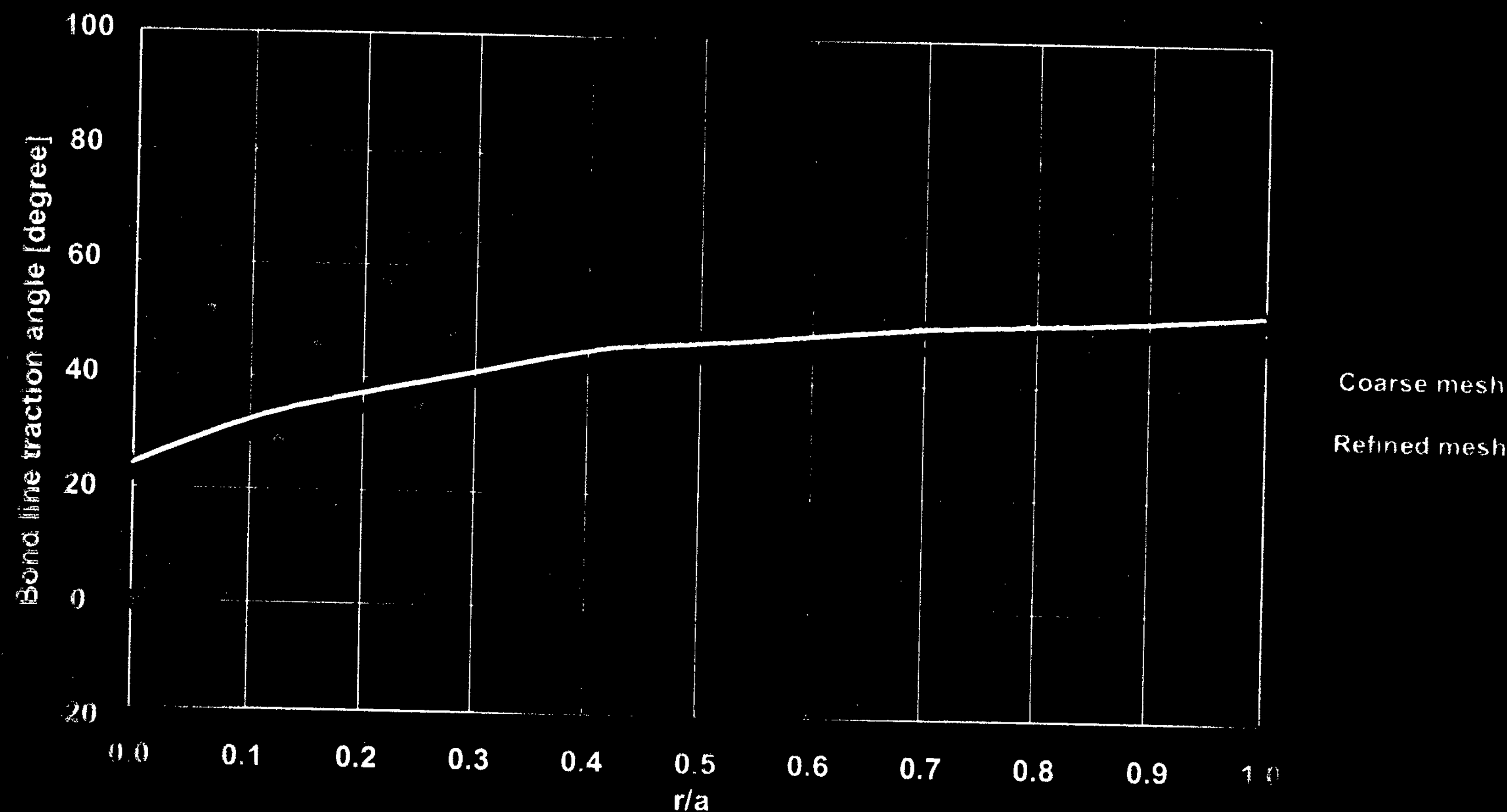
- T_{xy} and T_{yy} Averaged at Nodes Along y = o
- $\psi(r/a)$ is Cubic Fit of $\tan^{-1}[(T_{xy}/T_{yy})_{\theta=o}]$ vs. r/a
- $\Psi \equiv \tan^{-1}\left(\frac{K_{II}}{K_{II}}\right) = \lim_{r/a \to o} \psi(r/a)$




AIR FORCE RESEARCH LABORATORY
shear stress
kPa
-INF
+ 0
+ 19
+ 38
+ 56
+ 75
+ 94
+ 113
+ 132
+ 150
+ 169
+ 188
+ 207
+ INF
Crack angle = 0 deg.
Crack angle = 15 deg.
Crack angle = 30 deg.
Crack angle = 45 deg.


AIR FORCE RESEARCH LABORATORY
σ_{xy} [kPa]
-510
0
9
19
28
38
47
56
66
75
85
94
103
896
Crack angle = 0 deg.
Crack angle = 15 deg.
Crack angle = 30 deg.
Crack angle = 45 deg

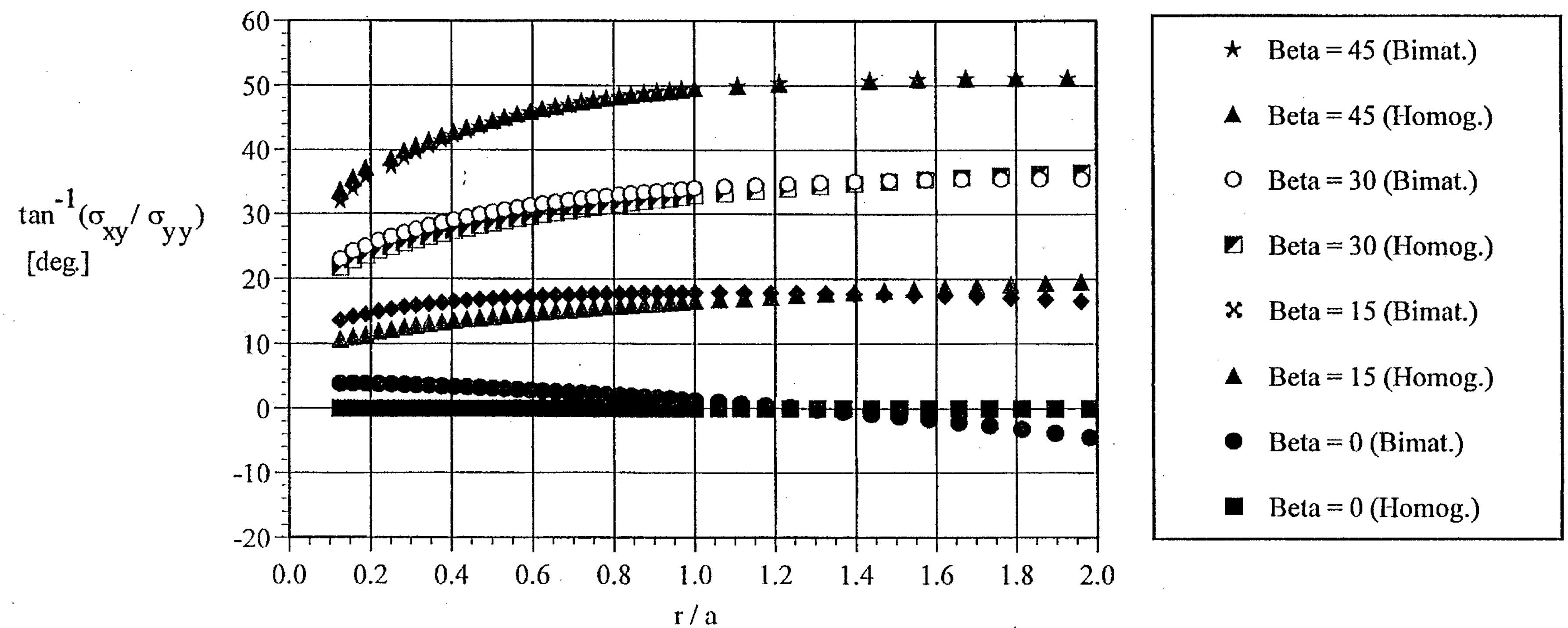

AIR FORCE RESEARCH LABORATORY
σ_{yy} [kPa]
-182
0
25
50
75
100
125
150
175
200
225
250
275
2530
Crack angle = 0 deg.
Crack angle = 15 deg.
Crack angle = 30 deg.
Crack angle = 45 deg.



Bond line traction angle [degree]
100
80
60
40
20
0
-20
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
r/a
Coarse mesh
Refined mesh

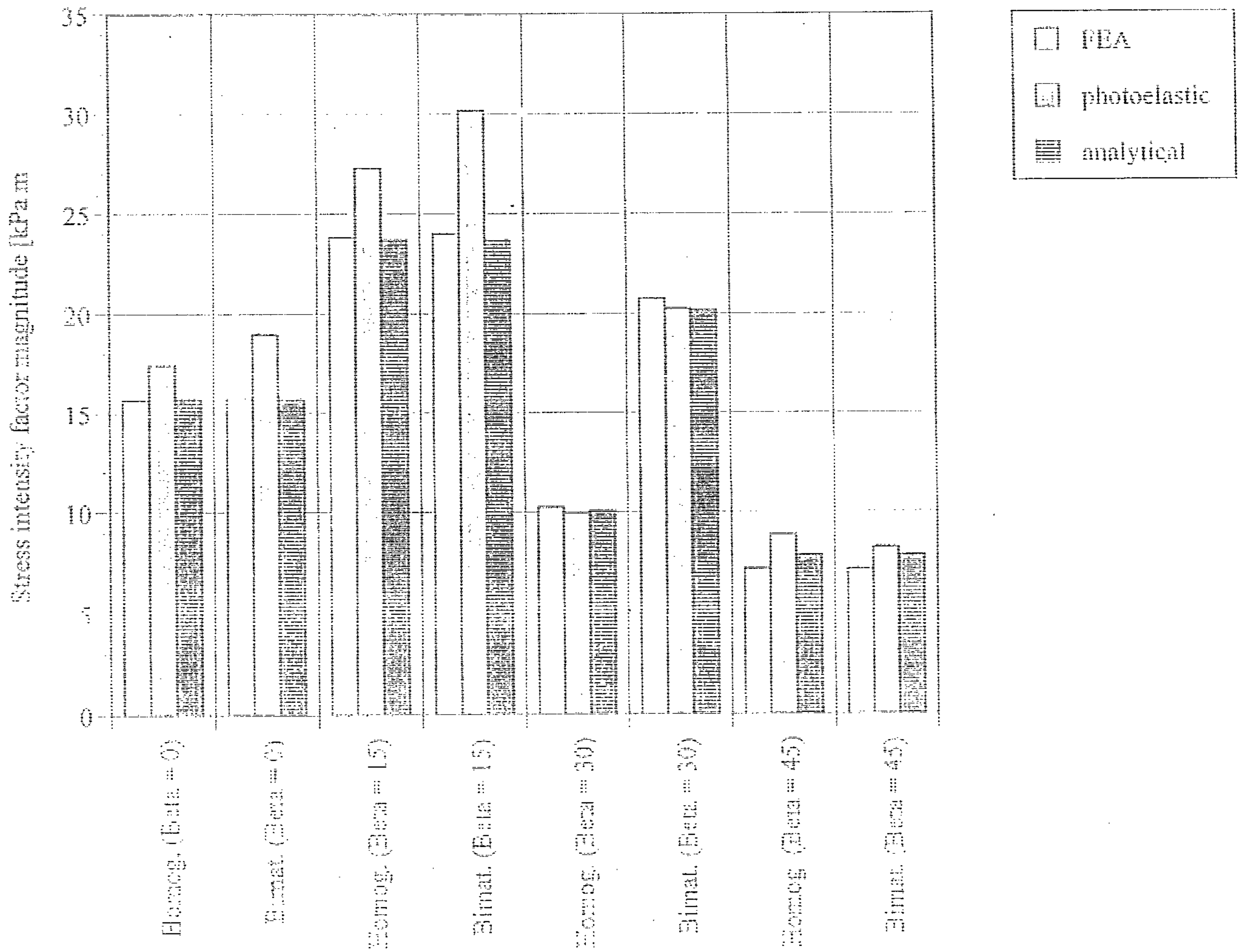
Phase Angle Extrapolation

Phase Angle is Evaluated from Bond Line Tractions Near Crack Tip



Stress Intensity Factor Magnitude Comparisons

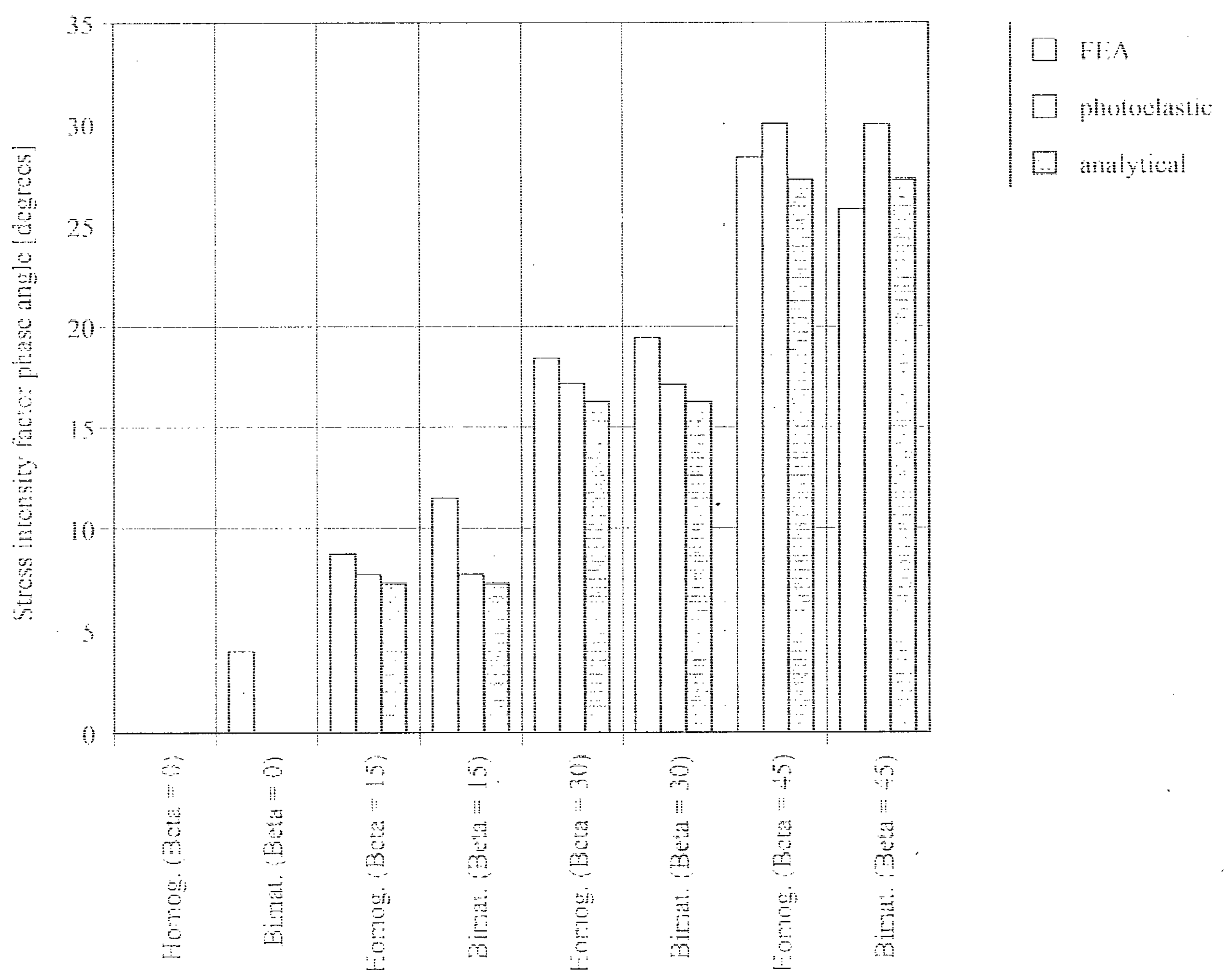
(Comparison of Numerical and Photoelastic Results)



B2588.

Stress Intensity Factor Phase Angle Comparisons

(Comparison of Numerical and Photoelastic Results)

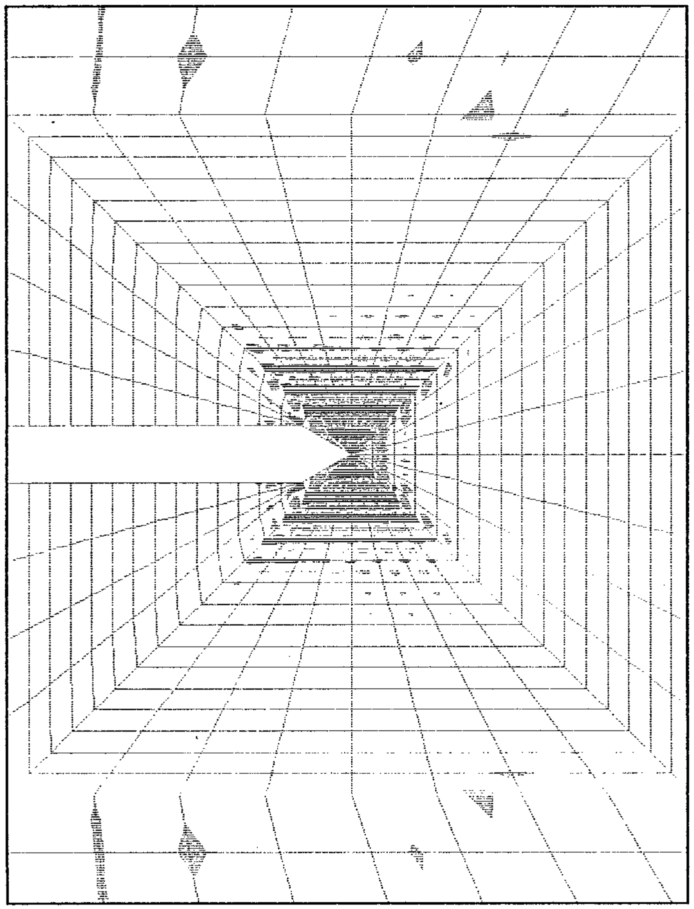


B2588.

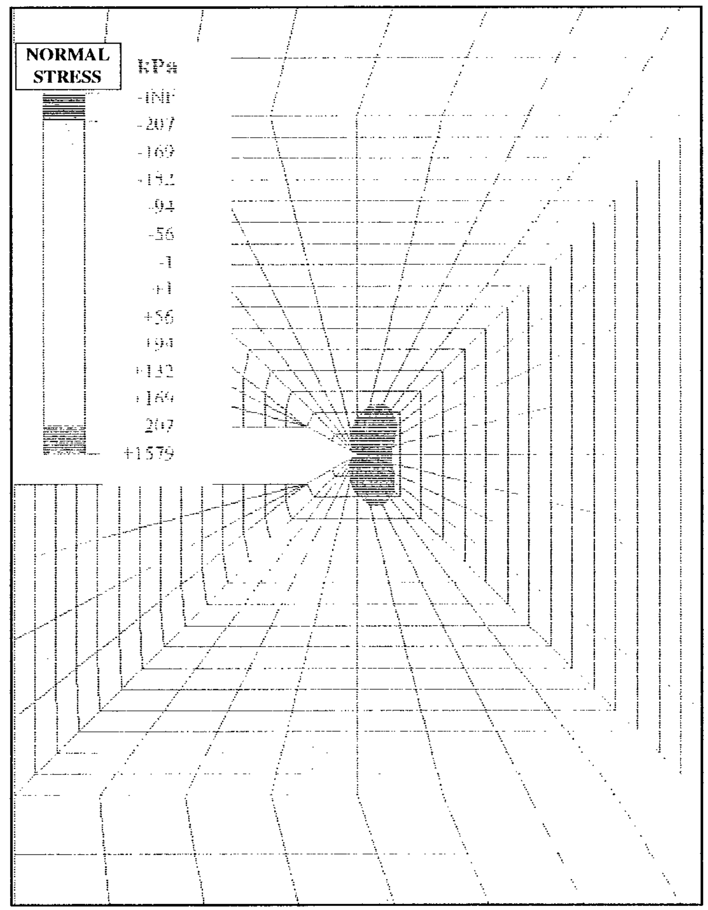
AIR FORCE RESEARCH LABORATORY

Hybrid Elements and Mixed Formulation Prevent Ill-Conditioning Problems

Conventional Formulation



Mixed Formulation



Conclusions

- Simplified field expressions can be used with incompressible bimaterials under plane strain conditions. The use of a mixed formulation and quarter point nodes are required for successful determination of the complex stress intensity factor $\vec{K} = K_I + i\,K_{II}$
- The Magnitude of the complex stress intensity factor can be determined by using area integration methods to determine the J integral and then converting J to K using effective plane strain modulus.
- The phase angle of the complex stress intensity factor can be determined by finding the limit as $r/a \rightarrow 0$ of a polynomial curve fit of $\tan^{-1}[(\sigma_{xy}/\sigma_{yy})_{\theta=o}]$ in a region near the crack tip.

- Experimental results and data - Dr. C.W. Smith, Virginia Polytechnic Institute and State University
- Funding and Computational Facilities - Dr. C.T. Liu, Air Force Research Laboratory, Edwards Air Force Base, California